ERDA/NASA 1022/77/13
NASA TM X-73657

(NASA-TM-X-73657) EFFECTS OF OUTDOOR EXPOSURE ON SOLAR CELL MODULES IN THE ERDA/NASA LEWIS RESEARCH CENTER SYSTEMS TEST FACILITY (NASA) 17 p HC A02/MF A01 CSCL 10A

N77-26678

Unclas
G3/44 31862

EFFECTS OF OUTDOOR EXPOSURE ON SOLAR CELL MODULES IN THE ERDA/NASA LEWIS RESEARCH CENTER SYSTEMS TEST FACILITY

I. Weinberg, Henry B. Curtis, and Americo F. Forestieri
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

April 1977

Prepared for
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Office of the Assistant Administrator for
Solar, Geothermal, and Advanced Energy Systems
Division of Solar Energy
Under Interagency Agreement E(49-26)-1022

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-73657		

4. Title and Subtitle	5. Report Date
EFFECTS OF OUTDOOR EXPOSURE ON SOLAR CELL MODULES IN THE ERDA/NASA LEWIS RESEARCH CENTER SYSTEMS TEST FACILITY	April 1977
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
I. Weinberg, Henry B. Curtis, and Americo F. Forestieri	E-9173

9. Performing Organization Name and Address	10. Work Unit No.
National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135	11. Contract or Grant No.
	13. Type of Report and Period Covered
	Technical Memorandum

12. Sponsoring Agency Name and Address	14. Sponsoring Agency ~~Code~~ Report No.
Energy Research and Development Administration Division of Solar Energy Washington, D.C. 20545	ERDA/NASA 1022/77/13

15. Supplementary Notes

Project report. Prepared under Interagency Agreement E(49-26)-1022.

16. Abstract

Solar cell modules were removed from the ERDA/NASA Lewis Research Center Systems Test Facility and I-V curves obtained in the Lewis pulsed xenon simulator under standard conditions (air mass 1 and 28^{o} C). Modules involved were supplied by three vendors under the ERDA/JPL Low Cost Silicon Solar Array Project. Outdoor exposure times varied from 41 to 245 days. The effects of outdoor exposure were determined by comparing standard I-V data obtained for the as-received modules with similar data obtained after removal from the field and cleaning with detergent solution. All modules measured in this way exhibited nonrecoverable degradation in P_{max} varying from 4 to 7 percent and I_{sc} varying from 2 1/2 to 5 1/2 percent. One module exposed for 41 days exhibited partial cell discoloration, loss of front surface metallization over the discolored portion, and a decrease in P_{max} of 7 percent, tentatively attributed to cell damage. Measurements before and after cleaning showed a recoverable degradation due to dirt accumulation. This recoverable loss in power was 11 percent after 245 days in the field for one brand of module, 6 percent after 48 days for another brand, and 4 1/2 percent for the third brand.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Solar cells Degradation Terrestrial Endurance	Unclassified - unlimited STAR Category 44 ERDA Category UC-63d

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

E-9173

EFFECTS OF OUTDOOR EXPOSURE ON SOLAR CELL MODULES IN THE ERDA/NASA LEWIS RESEARCH CENTER SYSTEMS TEST FACILITY

by I. Weinberg, Henry B. Curtis, and Americo F. Forestieri

Lewis Research Center

SUMMARY

Solar Cell modules were removed from the ERDA/NASA Lewis Research Center Systems Test Facility and I-V curves obtained in the Lewis pulsed xenon simulator under standard conditions (air mass 1 and 28° C). Modules involved were supplied by three vendors under the ERDA/JPL Low Cost Silicon Solar Array Project. Outdoor exposure times varied from 41 to 245 days. The effects of outdoor exposure were determined by comparing standard I-V data obtained for the as-received modules with similar data obtained after removal from the field and cleaning with detergent solution. All modules measured in this way exhibited nonrecoverable degradation in P_{max} varying from 4 to 7 percent and I_{sc} varying from 2 1/2 to 5 1/2 percent. One module exposed for 41 days exhibited partial cell discoloration, loss of front surface metallization over the discolored portion, and a decrease in P_{max} of 7 percent, tentatively attributed to cell damage.

Measurements before and after cleaning showed a recoverable degradation due to dirt accumulation. This recoverable loss in power was 11 percent after 245 days in the field for one brand of module, 6 percent after 48 days for another brand, and 4 1/2 percent for the third brand.

INTRODUCTION

One of the major factors in determining whether or not photovoltaic electric power will be a viable source of energy in the future is the

lifetime of the solar cell modules. The Energy Research and Development Administration (ERDA) has established, as a goal of the National Photovoltaic Program, that low cost solar cell arrays be developed with a lifetime of 20 years. As part of the national program, JPL purchased a quantity of solar cell modules from various manufacturers. For identification purposes, this initial JPL purchase is designated as the "46 kW" procurement. Some of these 46 kW modules have been installed in the ERDA Photovoltaic Systems Test Facility located outdoors at the NASA Lewis Research Center in Cleveland, Ohio. The first of these modules was installed in early April 1976.

The effects of the environment on modules installed in the Systems Test Facility (STF) are of particular interest for several reasons: first because JPL needs data to begin evaluating the capability of different module designs towards attaining the ERDA lifetime goal, and second, because the modules in the STF are utilized in arrays whose voltage output is relatively high (approx 200 V dc). With respect to the latter point, little or no data exist regarding environmental effects on solar cell modules used in arrays delivering these relatively high output voltages. The objective of the present work is then to acquire data under standard, easily reproducible, laboratory conditions for modules both before and after exposure to the environment. The data so obtained are intended to serve as the beginning of a data base which will be used to evaluate the effects of environmental exposure and use on representative terrestrial solar cell modules used in the STF.

EXPERIMENTAL PROCEDURE

Measurements were carried out on modules supplied by three different vendors, designated brands X, Y, and Z for identification purposes. Brand X is an aluminum-backed module with silicone rubber encapsulant while brands Y and Z are fiberglass-epoxy-backed modules with silicone rubber encapsulant.

As a standard procedure, I-V curves were obtained under standard conditions (air mass 1 and 28° C), in the Lewis pulsed xenon simulator, for approximately 12 percent of the modules on receipt from the vendor. After exposure to the environment, selected modules were removed

from the STF and I-V curves obtained under the same standard conditions.

In performing these measurements, a reference cell typical of the cells in the modules was employed to monitor light intensity for each brand. These reference cells consisted of a 2 by 2 centimeter cell made from a representative circular cell supplied by each vendor. The standard cell was mounted in a holder and calibrated (ref. 1) as part of the ERDA/Lewis measurements and standards program.

Because of variation in delivery time and priority considerations, the modules were installed in the STF field at different times. Thus the duration of outdoor exposure for modules on which the present measurements were performed was 41 days for brand Z, 48 days for brand X, and 153 and 245 days for brand Y. On removal from the STF, the modules were found to be coated with dirt to varying degrees. After obtaining I-V curves in the dirt-covered condition, the modules were cleaned using Alconox detergent solution and I-V curves obtained on the cleaned modules. Degradation data were obtained by comparing the I-V curves for the cleaned modules to those obtained at the time that the same modules were received from the vendor. Because of the sampling method employed, as modules were received from the vendor, I-V curves obtained before field installation were not available for all modules removed from the STF. For these modules, data obtained after exposure and before and after cleaning were used to obtain a numerical measure of the effects of dirt accumulation on module performance.

RESULTS AND DISCUSSION

Performance of Modules after Outdoor Exposure and Cleaning

Typical I-V curves before and after outdoor-exposure and subsequent cleaning are shown in figure 1 for the three module types. Data obtained from such curves are shown in table I for the modules before and after exposure and cleaning. The percent change after exposure

and cleaning is shown in table II.

With respect to the visually observed effects of outdoor exposure, brand X exhibited little or no weathering effects. The brand Y modules exhibited delamination of the encapsulant from the fiberglass backing; however, none of this delamination occurred over the encapsulated solar cells.

Aside from dirt accumulation, the only visually observed change to the brand Z module was a darken region over a portion of one cell (fig. 2). In addition, the front contact metallization had largely disappeared from the darkened portion of this cell. The cause of the partial cell darkening for this module is not known. In this connection, it is noted that the solid I-V curve shown in figure 1(c) resembles the I-V curve expected for an array with a partially shaded cell (ref. 2). Further work is necessary, however, to pinpoint the precise cause of I-V curve deterioration of brand Z.

The results shown in tables I and II indicate degradation of all brands to varying degrees. Module degradation is manifested most markedly by change with exposure in the parameters I_{sc}, the short circuit current, and P_{max}, the maximum power output. The short circuit current depends on light intensity and spectrum at the cell surface, spectral response and series resistance. For a standard spectrum the intensity and spectrum at the cell surface are affected largely by antireflection coating and encapsulant changes, while the spectral response and series resistance depend largely on cell and metallization characteristics.

It was anticipated that the encapsulant, antireflection coating, cells, and metallization would degrade to varying degrees with time for different modules. However, from table II the change in I_{sc} falls approximately within the same range for all modules. It is also noted that both the greatest and least change in I_{sc} is exhibited by the brand Y modules. Therefore it is not possible at this time to state that one brand exhibits a greater or lesser degree of degradation, when compared to the other two, by considering changes in I_{sc}.

The change in P_{max} is of great interest with respect to module performance. Degradation of any or all of the module and cell properties previously mentioned could lead to decreased P_{max}. From

table II all brands show approximately similar percentage decreases in P_{max}, despite the fact that brand Y has experienced a much greater exposure time than Z and X. It cannot be determined from these limited data whether brand Y has better weathering characteristic than the other two brands or that the loss in P_{max} tends to saturate at the same level.

Of the remaining parameters, the change in V_{max} is largest for brand Z, reflecting the changed I-V curve shape noted for this brand. Here the effect of possible cell damage in module Z appears to predominate. Finally, although a decrease in fill factor is noted for all modules, the change is relatively small and can be considered as insignificant.

Performance of Outdoor Exposed Modules

Before and After Cleaning

A number of other modules, were removed from the field and I-V curves obtained in the laboratory both before and after cleaning. These data can be used to assess the effects of dirt accumulation due to outdoor exposure. It is noted that during the last 3 months of the exposure period, excavation, bulldozing, and stand installation required for expansion of the field from 10 kW to 40 kW took place. Hence, the dirt accumulation was not linear with time.

Typical I-V curves obtained after exposure, before and after cleaning, are shown in figure 3. Average values of the electrical parameters for 25 modules are listed in table III and the percentage change observed in the electrical parameters as a result of cleaning are shown in table IV. For the parameters listed in the tables, I_{sc} and P_{max} are most sensitive to intensity change. Hence the effects of dirt accumulation are examined by observing the changes in these two parameters.

From table IV it is seen that the longer the time in the field, the greater the intensity alteration (as measured by the change in I_{sc} and P_{max}) due to dirt accumulation. However, the measured changes in I_{sc} and P_{max} are not directly proportional to time.

Another factor in dirt accumulation is the relative surface stickiness

of the three brands. Of the three modules types, brand Z has the surface which is smoothest to the touch. Presumeably, less dirt accumulation should occur for this module type. However, this can only be verified with modules exposed for equal periods of time under the same conditions.

SUMMARY OF RESULTS

Comparison of the I-V curves (measured under standard conditions) obtained after outdoor exposure and cleaning reveal a performance degradation for modules exposed for 153, 48, and 41 days, respectively. The most significant change is that observed in P_{max} the maximum power output of the module. For the modules observed P_{max} showed decreases, due to the exposure, from 4 to 7 percent. Despite a longer exposure time, brand Y, on the whole, did not show greater degradation than the remaining two brands. Partial cell darkening with relatively brief exposure was noted for a brand Z module. The I-V curve for this case is similar to that noted for an array with a partially shaded cell. Finally, comparison of the I-V curves for exposed modules both before and after cleaning shows recoverable power degradation of 4 1/2 to 11 percent due to dirt accumulation as a result of exposure in the Lewis Research Center systems test facility.

REFERENCES

1. Brandhorst, Henry; Hickey, John; Curtis, Henry; and Ralph, Eugene: Interim Solar Cell Testing Procedures for Terrestrial Applications. NASA TM X-71771, 1975.

2. Rauschenbach, H. S.: Electrical Output of Shadowed Solar Arrays. Proc. 7th IEEE Photovoltaic Specialists Conference, 1968, pp. 243-250.

TABLE I. - ELECTRICAL PARAMETERS FOR EXPOSED, CLEANED MODULES AND UNEXPOSED, AS RECEIVED MODULES

Module		Date in STF	Outdoor exposure, days	Before outdoor exposure (as received)					After outdoor exposure and cleaning				
Brand	Ser. No.			I_{sc}, A	V_{oc}, V	V_{max}, V	P_{max}, W	F.F., %	I_{sc}, A	V_{oc}, V	V_{max}, V	P_{max}, W	F.F., %
X	449	10/26/76	48	0.558	14.15	11.45	5.90	74.7	0.54	14.0	11.4	5.61	74.2
X	400	"	48	.538	14.08	11.5	5.83	77.0	.52	13.9	11.5	5.52	76.4
X	422	"	48	.533	14.08	11.68	5.93	79.0	.51	13.9	11.5	5.52	77.9
Y	1339	7/12/76	153	1.337	10.11	7.65	8.63	63.9	1.26	10.2	7.72	8.18	63.5
Y	1354	"	153	1.374	10.11	7.66	8.83	63.6	1.34	10.2	7.8	8.5	62.2
Y	1360	"	153	1.328	10.18	7.57	9.01	66.6	1.26	10.1	7.65	8.42	66.2
Z	7660310	11/2/76	41	1.465	12.90	10.20	14.08	74.5	1.42	12.7	9.90	9.90	13.1

TABLE II. - PERCENT CHANGE, FROM THE AS-RECEIVED UNEXPOSED CONDITION, AFTER OUTDOOR EXPOSURE AND CLEANING

Module		Outdoor exposure, days	Percent change after outdoor exposure and cleaning				
Brand	Ser. No.		I_{sc}	V_{oc}	V_{max}	P_{max}	F.F.
X	449	48	-3.2	-1.1	-0.4	-4.9	-0.7
X	400	48	-3.4	-1.3	0.0	-5.3	-.8
X	422	48	-4.3	-1.3	-1.5	-6.8	-1.4
Y	1339	153	-5.5	..9	.9	-5.2	-.6
Y	1354	153	-2.5	.9	1.9	-3.7	-2.1
Y	1360	153	-5.1	-.8	1.1	-5.2	-.6
Z	7660310	41	-2.8	-1.6	-2.9	-6.1	-2.1

TABLE III. - AVERAGE ELECTRICAL PARAMETERS OF EXPOSED CLEANED MODULES AND EXPOSED-UNCLEANED MODULES

Module brand	No. of modules evaluated	Date in STF	Days in STF	Average values after exposure in STF									
				Before cleaning					After cleaning				
				I_{sc}, A	V_{oc}, V	V_{max}, V	P_{max}, W	F.F., %	I_{sc}, A	V_{oc}, V	V_{max}, V	P_{max}, W	F.F., %
X	3	10/26/76	48	0.49	13.9	11.53	5.24	76.5	0.52	13.9	11.47	5.55	76.2
Y	16	4/12/76	245	1.192	10.04	7.34	7.47	62.5	1.302	10.09	7.44	8.29	63.0
Z	6	11/2/76	41	1.377	12.39	9.57	12.52	73.4	1.437	12.55	10.20	13.09	72.7

TABLE IV. - PERCENT CHANGE IN MODULE PARAMETERS DUE TO CLEANING OF EXPOSED MODULES

Module brand	No. of modules evaluated	Date in STF	Days in STF	Percent change in average values due to cleaning after exposure				
				I_{sc}	V_{oc}	V_{max}	P_{max}	F.F.,
X	3	10/26/76	48	6.1	0.0	-0.5	5.9	-0.4
Y	16	4/12/76	245	9.2	.5	1.4	11.0	.8
Z	6	11/2/76	41	4.4	1.3	6.6	4.6	1.0

FIGURE 1-A: I-V CURVES, BRAND "X" (449) EXPOSED 48 DAYS

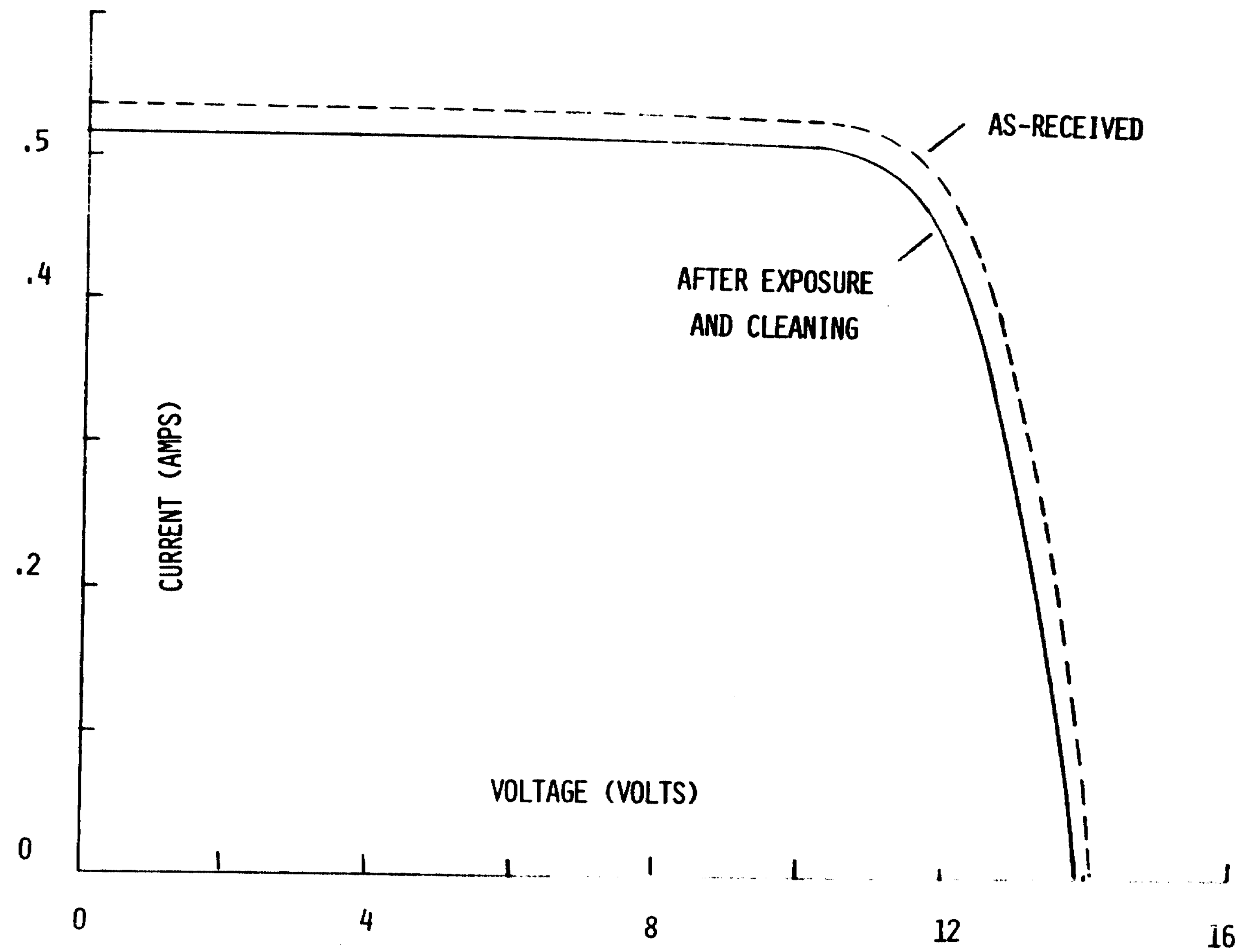

FIGURE 1-B: I-V CURVES, BRAND "Y" (#1339)
EXPOSED 153 DAYS

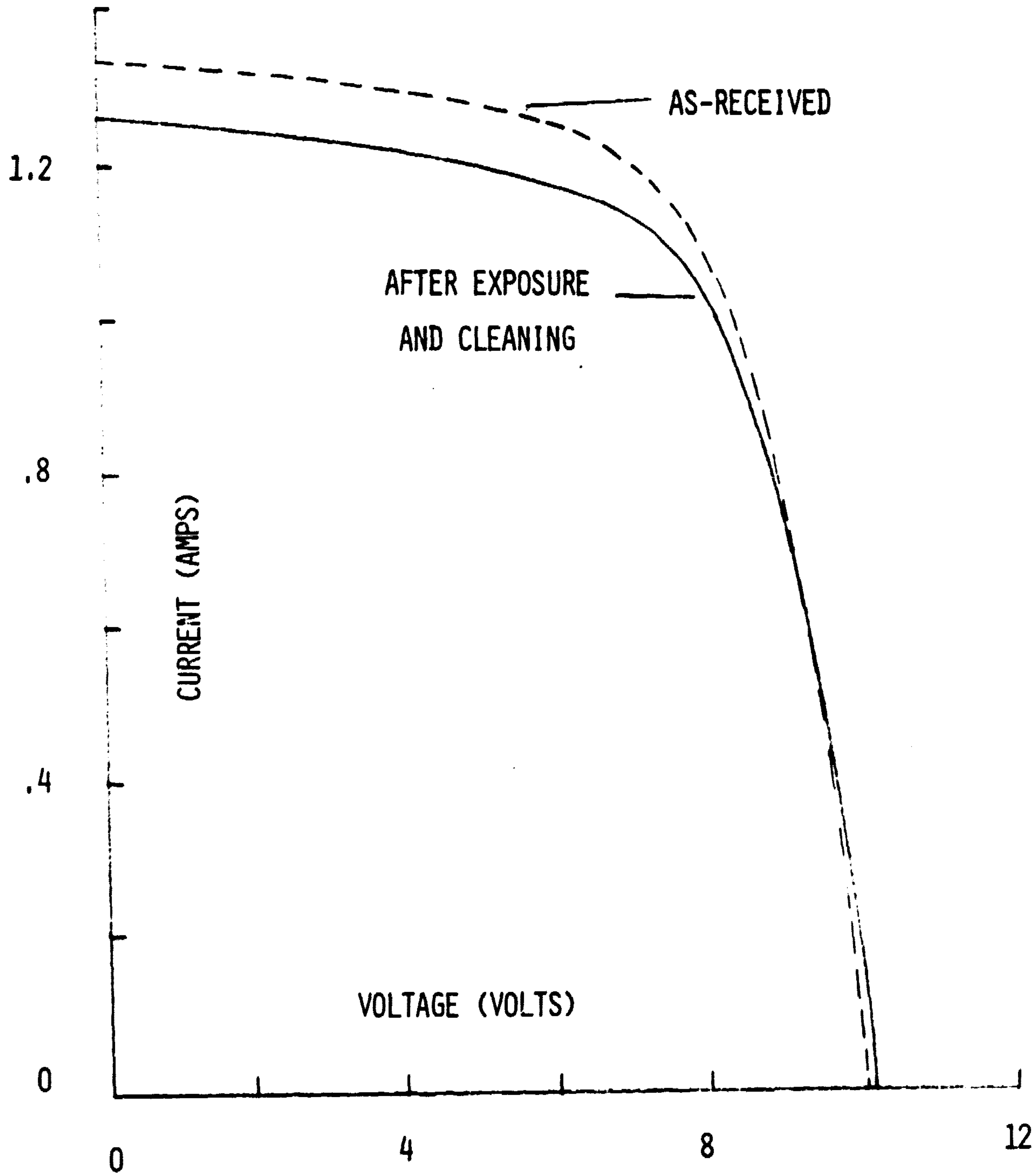

FIGURE 1-C: BRAND "Z" (#7660310)
EXPOSED 41 DAYS

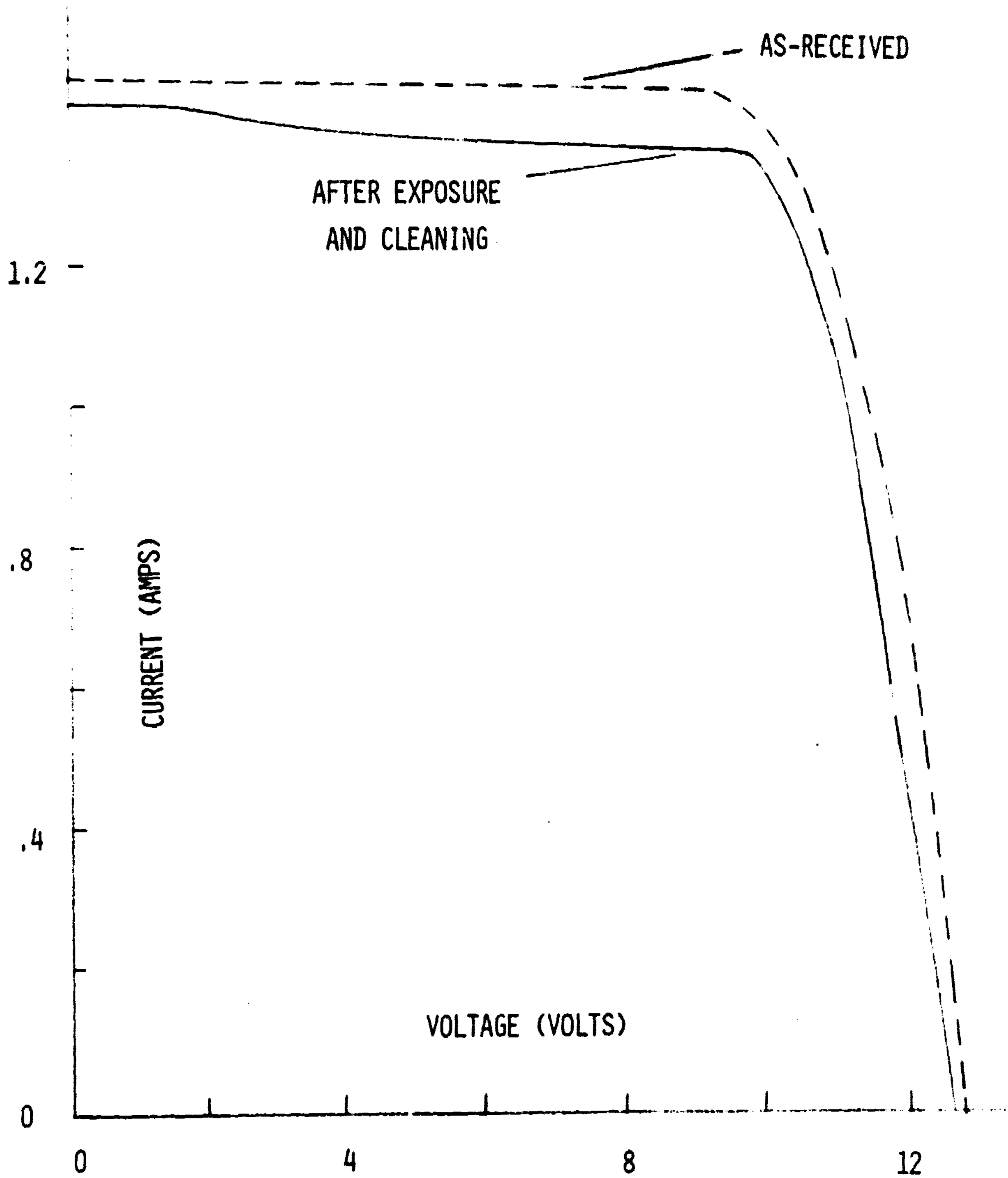

FIGURE 2: BRAND "Z" (#7660310) SHOWING DARKENED PORTION

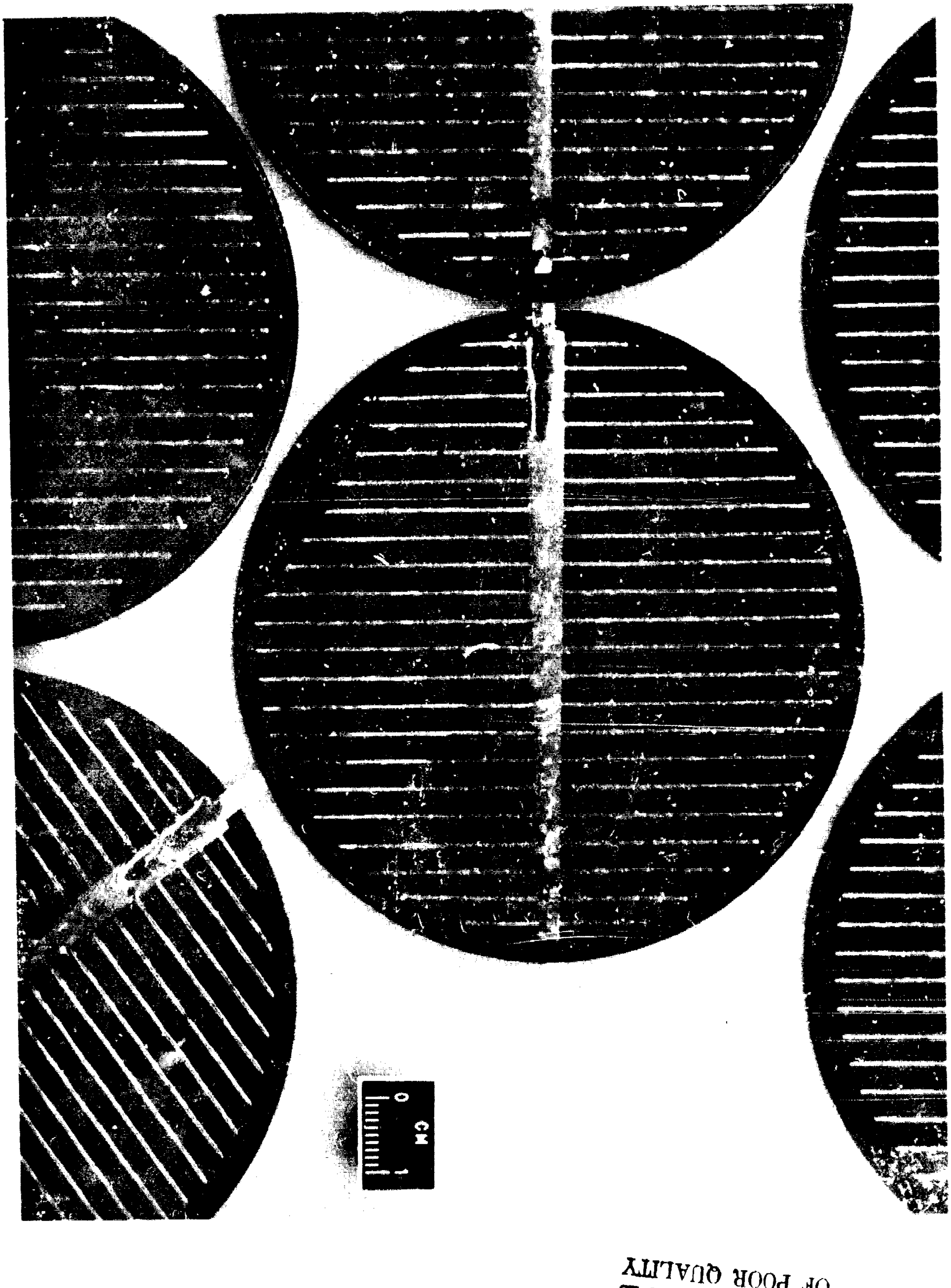

FIGURE 3-A: EFFECTS OF DIRT ACCUMULATION

BRAND "Y", (#1315) 245 DAYS OUTDOOR EXPOSURE

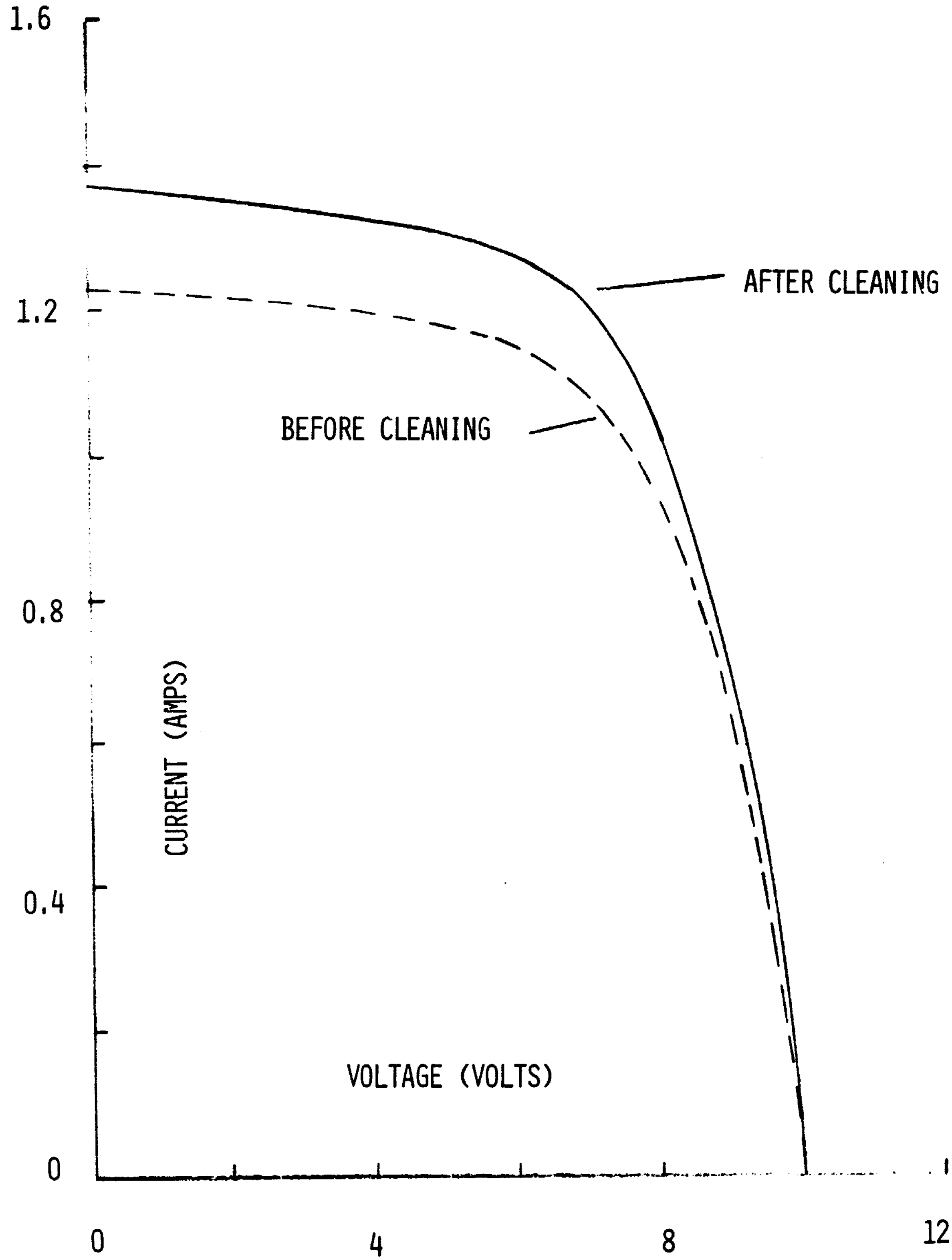

FIGURE 3-B: EFFECTS OF DIRT ACCUMULATION
BRAND "Z" (#7660309); 41 DAYS OUTDOOR EXPOSURE

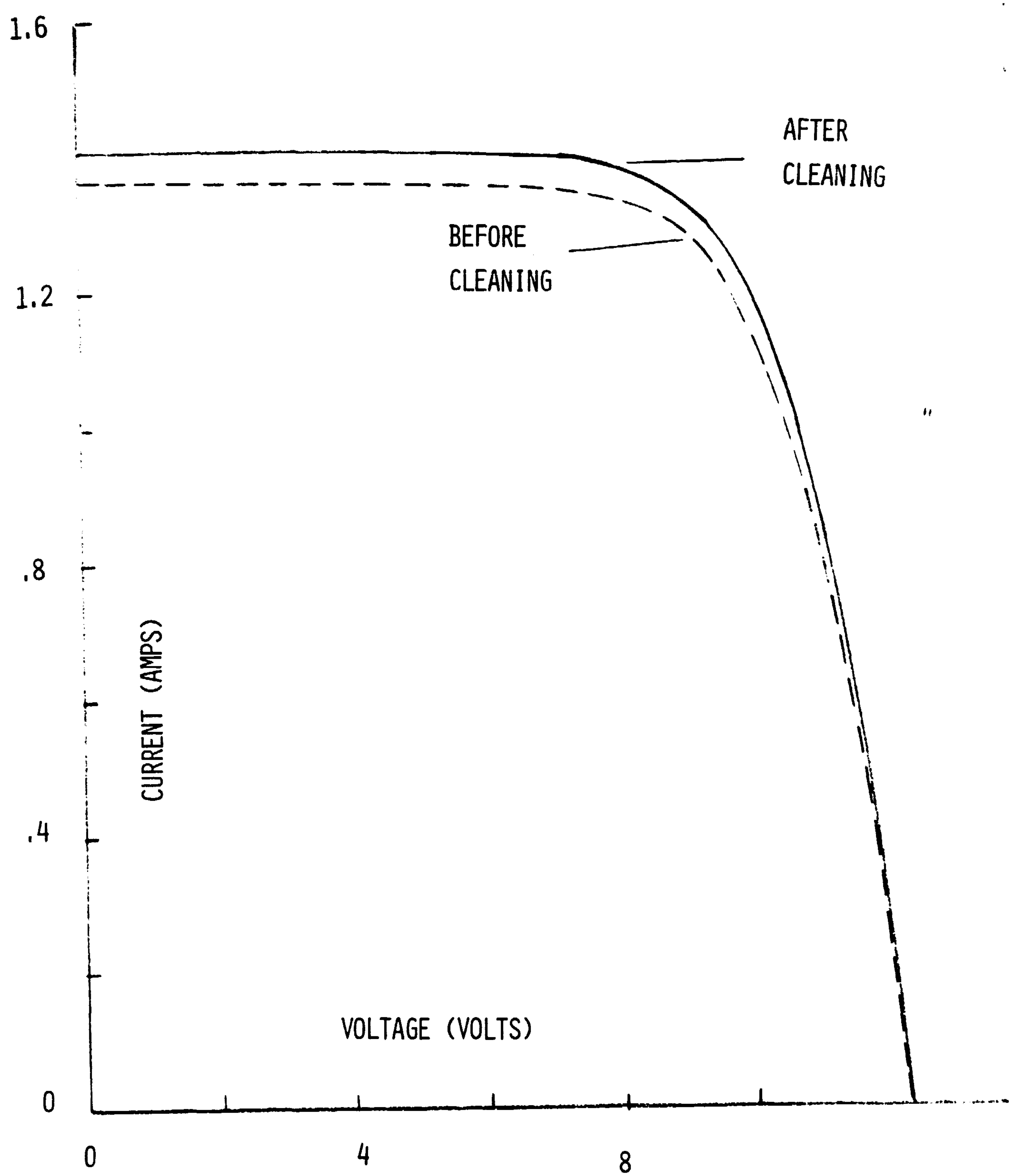

FIGURE 3-C: EFFECTS OF DIRT ACCUMULATION

BRAND "X" (#400), 48 DAYS OUTDOOR EXPOSURE